

Some Aspects on the Mechanical Analysis of Micro-shutters

Rainer K. Fettig^a, Jonathan L. Kuhn^b,
S. Harvey Moseley^b, Alexander S. Kutryev^a,
Jon Orloff^c, and Shude Lu^c

^aRaytheon ITSS, Greenbelt, MD
^bNASA/Goddard Space Flight Center, Greenbelt,
MD
^cDepartment of Electrical Engineering,
University of Maryland, College Park, MD

Abstract

An array of individually addressable micro-shutters is being designed for spectroscopic applications. Details of the design are presented in a companion paper[1]. The mechanical design of a single shutter element has been completed. This design consists of a shutter blade suspended on a torsion beam manufactured out of single crystal silicon membranes. During operation the shutter blade will be rotated by 90 degrees out of the array plane. Thus, the stability and durability of the beams are crucial for the reliability of the devices. Structures were fabricated using focused ion beam milling in a FEI 620 dual beam machine, and subsequent testing was completed using the same platform. This allowed for short turn around times. We performed torsion and bending experiments to determine key characteristics of the membrane material. Results of measurements on prototype shutters were compared with the predictions of the numerical models. The data from these focused studies were used in conjunction with experiments and numerical models of shutter prototypes to optimize the design. In this work, we present the results of the material studies, and assess the mechanical performance of the resulting design.

Introduction

Micro-electromechanical systems (MEMS) technology has spurred development of arrays of individually controlled active elements. While the majority of researchers have focused on reflective micro-mirror arrays, transmissive designs provide much lower scattered light and higher contrast. As a result, Moseley et. al.[1] developed a micro-shutter array design for astronomical applications.

Proposed transmissive micro-shutter design:

- 1000 by 1000 array
- 80% fill factor
- 100 by 100 μm blade
- Torsion beam edge suspension for 90 degree rotation

In this work, key aspects of the design of a single micro-shutter (Fig. 1) are addressed through simplified numerical, analytical, and experimental techniques.

Procedure:

- Measure the Young's modulus using a vibration test (Fig. 2)
- Determine minimum fracture strength using a bending test (Fig. 3)
- Calculate the maximum shear stress using beam equations (Fig. 4)
- Simulate the micro-shutter using finite element analysis (Fig. 5)
- Demonstrate 180 degree rotation (Fig. 6)

Materials and Experimental Techniques

High strength membrane materials suspended on anisotropically etched (KOH) silicon substrates:

- Single crystal silicon - 2.0 μm thick
- Low stress CVD silicon nitride - 0.5 μm thick

Microfabrication and testing in a FEI 620 machine with:

- Focused ion beam milling
- *In situ* scanning electron microscopy
- MOCVD platinum deposition
- Micro-manipulated needle

Results

Vibration Test

Material	Cross-section	Frequency	Modulus
Silicon	20 x 1.9 μm	12600 Hz	155 GPa
Silicon Nitride	9 x 0.55 μm	17800 Hz	220 GPa

Bending Test

Material	Cross-section	Strength
Silicon	6.25 x 1.9 μm	9.4 GPa
Silicon Nitride	2.1 x 0.55 μm	16.9 GPa

Conclusion

A preliminary design of the basic micro-shutter element used in a micro-shutter array has been completed. The micro-shutter finite element results appeared to be consistent with the preliminary strength data presented herein. While the approach is approximate, strong agreement was observed between the simplified equations, finite element models, and tests. As a result the simplified equations can be used to understand design trade-offs and are adequate to help guide the design. Once an initial design is selected based on these equations and tests, the structure can be simulated with detailed finite element analysis for further refinement and flight qualification analysis. Silicon nitride was found to be more resistant to failure for the set of dimensions used in the study.

Acknowledgments

The authors greatly acknowledge the following:

- Grant from NGST/GSFC 98-01
- Christine Allen from NASA/GSFC Code 553
- Tina Chen from Global Science and Technology

[1] S.H. Moseley, R.K. Fettig, A.S. Kutryev, C.W. Bowers, R.A. Kimble, J. Orloff, and B.E. Woodgate, "Programmable 2-dimensional micro-shutter arrays," in *Micromachining and Microfabrication, Proceedings of SPIE 3878*, Sept. 1999

Single Micro-shutter Geometry

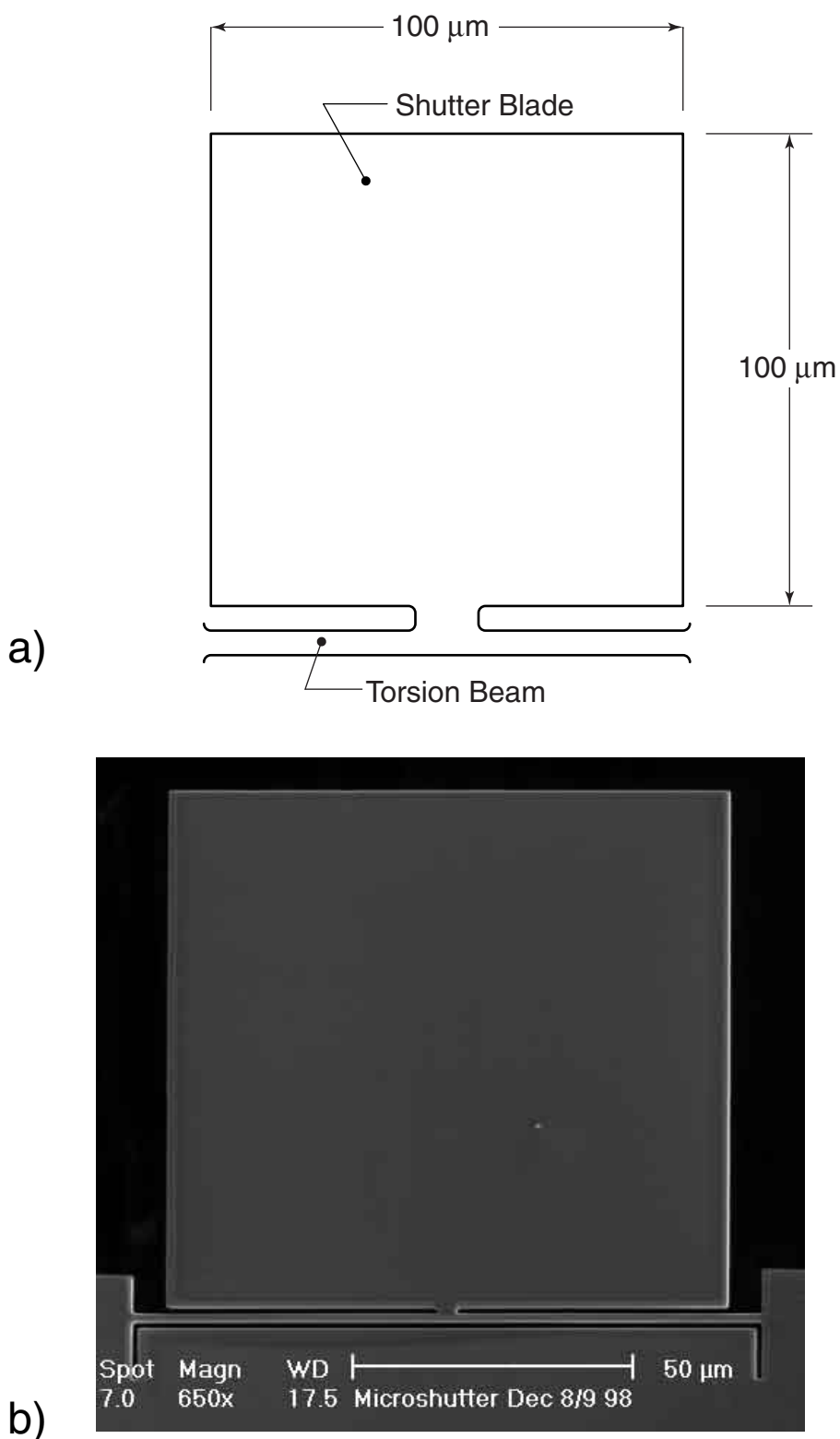


Figure 1: A single micro-shutter is comprised of a large blade suspended from torsion bars. a) Schematic drawing depicting the dimensions. b) Scanning Electron Micrograph (SEM) of a fabricated shutter.

Material Stiffness Test Specimen

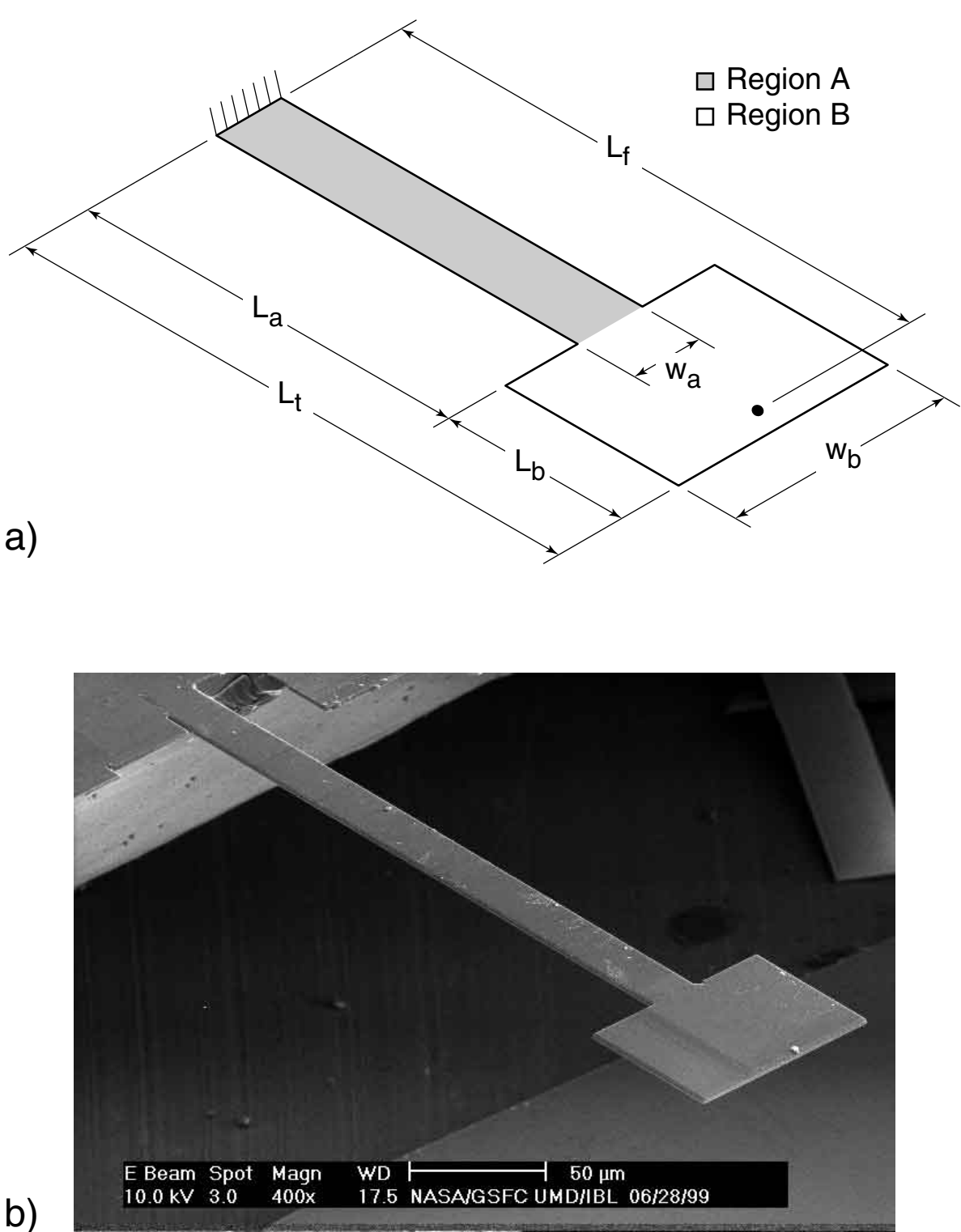


Figure 2: The Young's modulus is determined by measuring the natural frequency of the above specimen. a) Schematic showing the specimen dimensions. b) SEM of a fabricated test beam.

Material Strength Test Specimen

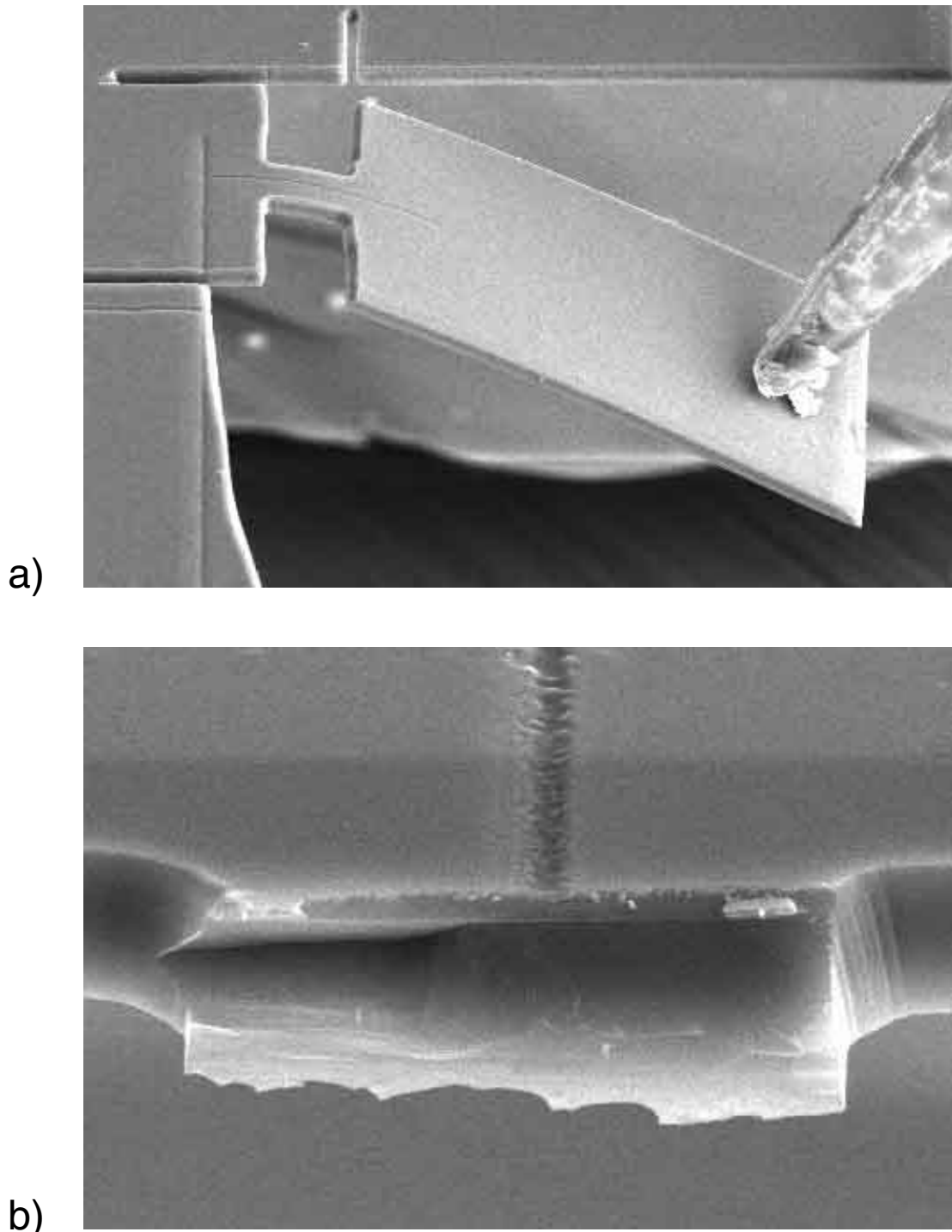


Figure 3: The fracture strength is determined by measuring the deflection of the above specimen. a) A fabricated test specimen prior to failure. b) Fracture surface after specimen failure.

Effect of Torsion Beam Width and Thickness

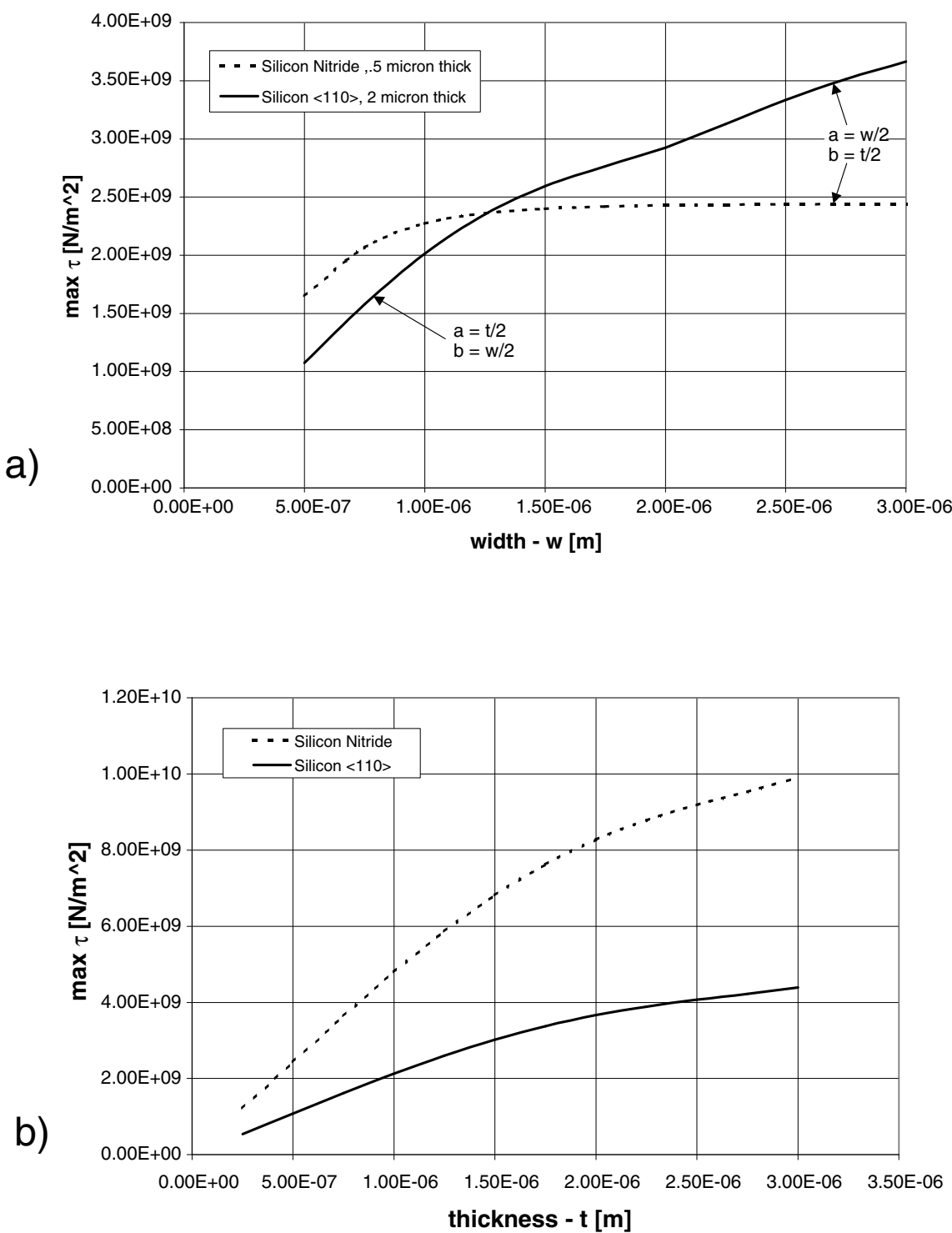


Figure 4: Maximum shear stress at 90 degree tilt for torsion beam 100 μm long versus a) width and b) height.

Micro-shutter Finite Element Model

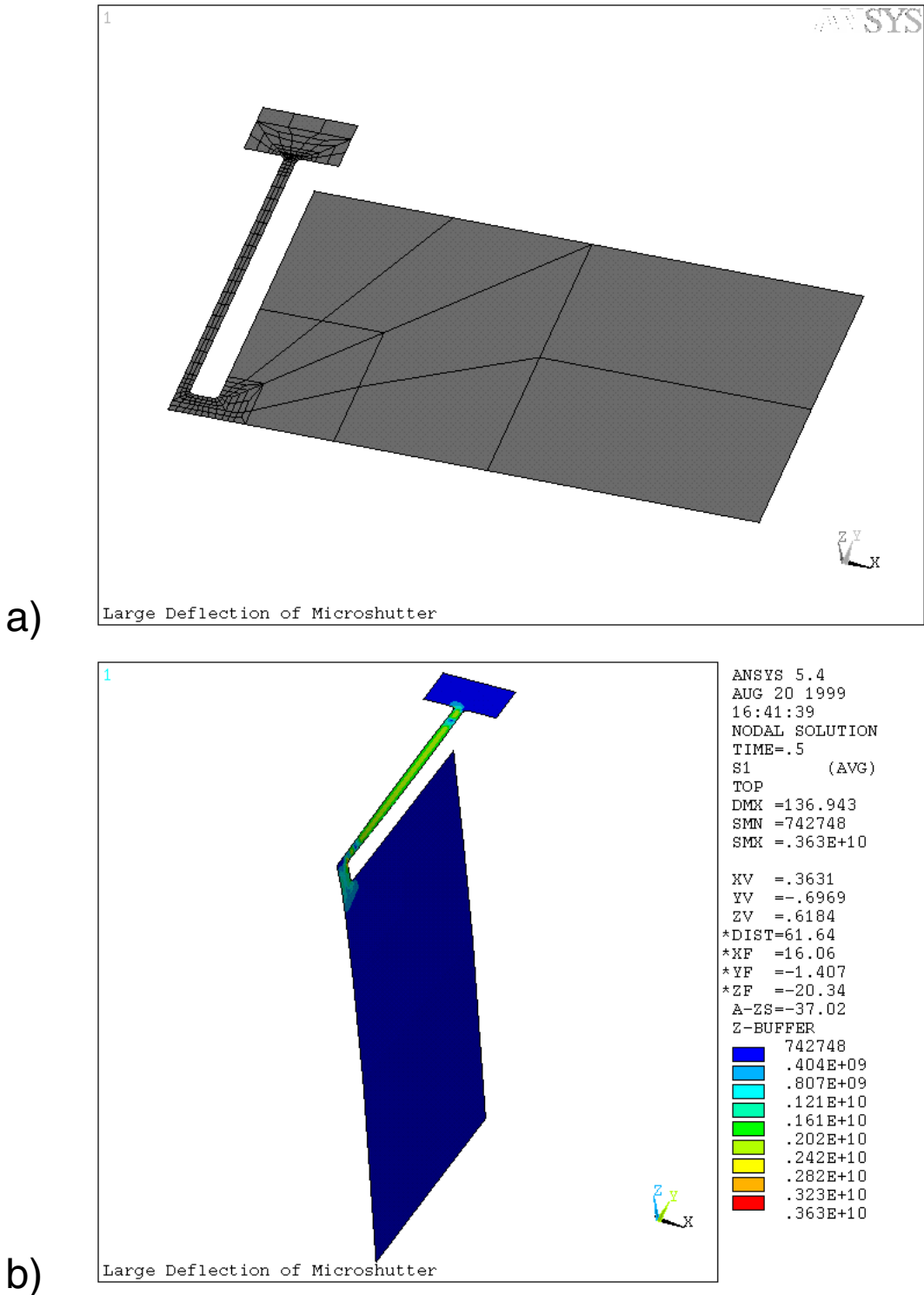


Figure 5: Finite element model of the micro-shutter created using ANSYS. a) Undeformed finite element mesh. b) Contour fringes of the maximum principal stress at 90 degree tilt.

Micro-shutter Deformation Sequence

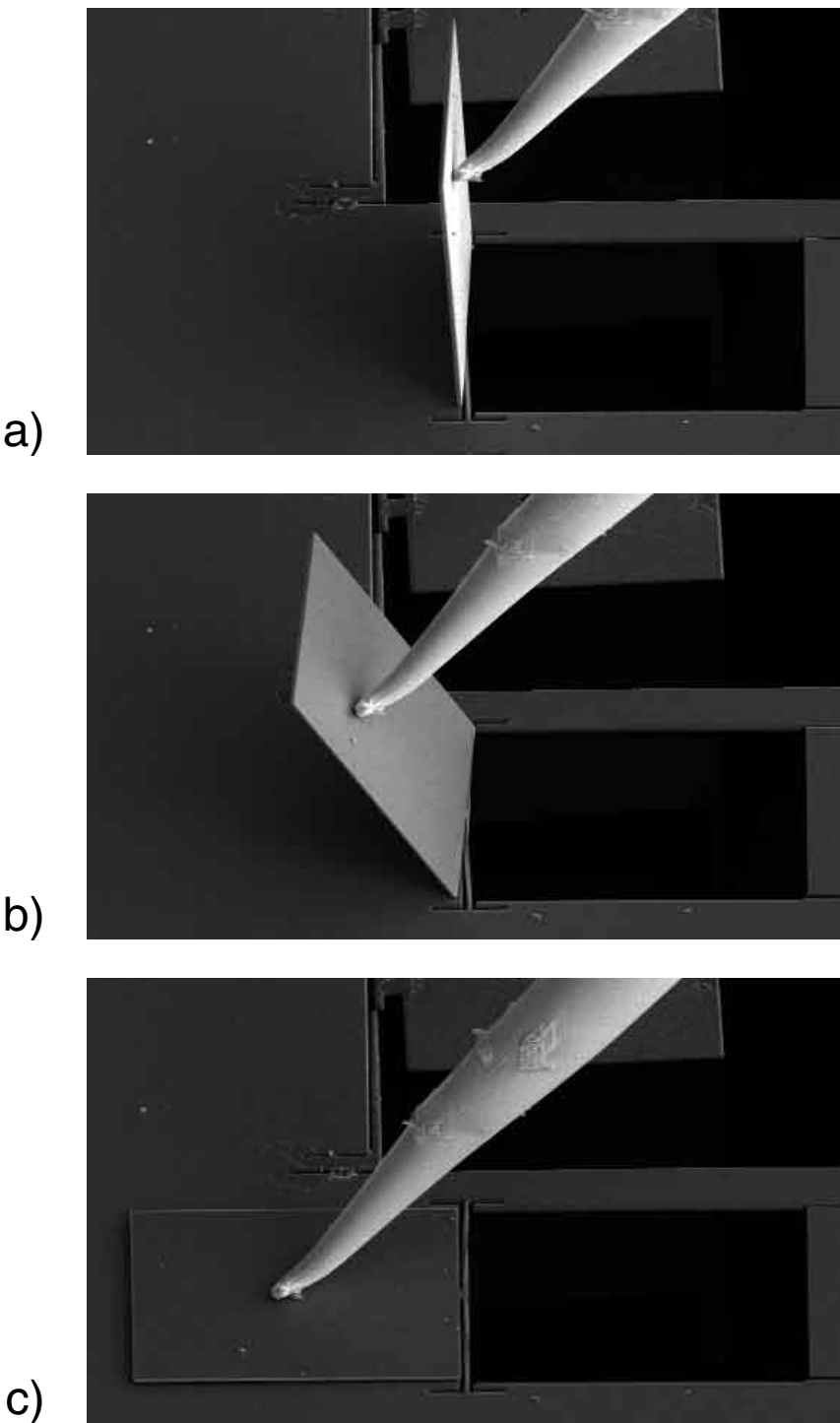


Figure 6: SEM of a micro-shutter rotated approximately a) 90, b) 135, and c) 180 degrees.